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RECENT DEVELOPMENT AND PERSPECTIVES OF COMMUNICATIONS SATELLITES

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**/1

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A review of existing communications satellites, including TELSTAR, RELAY, SYNCOM, EARLY BIRD, MOLNYA, etc., with tabulated data on worldwide coverage of the systems, main characteristics, and orbital aspects, is followed by a brief discussion of European projects and future participation in US projects. Advantages of phased and clustered systems are compared, and European preference for 24-hour orbit systems is emphasized. A French project of a three-orbit system with groups of 4 - 5 satellites each and a 12-hour circular orbit at 20,400 km is described briefly.

author

INTRODUCTION

Last May, the International Union of Telecommunications celebrated the anniversary of the first international agreement on communications, signed in Paris at the Quai d'Orsay a century ago. Today, communications satellites offer possibilities that were not even thought of several years back. We are living in a period of transition between the experimental phase and the beginning of operational exploitation. Some controversies with respect to the tariff proposed by the Communications Satellite Corporation (Comsat), the US corporation controlled by an International Committee, are proof of this.

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** Numbers in the margin indicate pagination in the original foreign text.

The purpose of this paper is the following:

Describe the most outstanding characteristics of long-distance communications by satellites.

Review the requirements of traffic and the presently available systems for satisfying these requirements.

Compare the proposed solutions for realization of the satellites.

List the European possibilities.

EXCLUSIVE PROPERTIES OF COMMUNICATIONS SATELLITES /2

Let us first list the various precursors:

TELSTAR I, developed by the American Telephone and Telegraph Co. (AT&T) and launched on July 10, 1962 into an elliptical orbit (5600 km to 950 km) inclined by 45° to the Equator.

RELAY I, constructed by the Radio Corp. of America (RCA), under contract with the National Aeronautics and Space Administration (NASA) and launched December 13, 1962 into a similar orbit.

SYNCOM II, designed by Hughes Aircraft for NASA and launched July 26, 1963 into a 24-hour circular orbit, i.e., synchronous with the rotation of the earth.

We all have become conscious of the intrinsic possibilities of satellites, which include the following:

Reliable long-range connections, comparable to underseas cables without the latter's limitation in frequency bandwidth.

Wide frequency bands, ensuring transmission of television and multiplex high-capacity telephony, comparable to Hertzian beams without the latter's limitation in range.

Novel possibility, from one and the same satellite, to connect at will any two of the large number of ground stations which, individually, have a relatively low traffic (technique of multiple access).

Possibility, from one and the same satellite, to cover, by long-distance diffusion, a geographic zone of previously never reached dimensions.

By realizing these advantages, individually or in combination, the communications satellites will be highly successful in their particular fields of application.

TRAFFIC AND SYSTEMS 13

The commercially most immediate motivation for building communications satellites is for international telephone connections. Three different schools of thought have formed from the very beginning, with respect to the system or type of orbit:

Narrow-pass or medium-altitude satellites with random orbit, advocated by AT&T and RCA.

Medium-altitude satellites with controlled orbital position, known as phased systems and sponsored by TRW and ITT.

Geostationary satellites, pushed by Hughes Aircraft.

The random-orbit satellite system,although it facilitates the problems of insertion into orbit and satellite design, has several drawbacks for exploitation, as indicated in Table 1. For example, it is difficult to become reconciled to complete interruption in long-distance communications, even if the date and duration are predictable. This was the main reason for the decision by COMSAT to abandon the random-orbit satellite type.

We should mention that the Eurospace Working Group for communications

TABLE 1

COMPARATIVE COVERAGE OF PHASED AND RANDOM SYSTEMS
(COMMUNICATION LINE NORTH ATLANTIC)

Type of System	Knocked-Out Satellites	Percentage of Time during which N Satellites are Visible			Mean Time of Interruption (min.)	Number of Days between Interruptions
		N = 1	N = 2	N = 3		
Phased 2 x 6	0	100	100	77.01	None	
" "	1	100	96.17	59.56	"	
Phased 2 x 8	0	100	100	100	"	
" "	1	100	100	93.39	"	
" "	2	100	99.10	85.11	"	
" "	3	99.94	97.08	75.60	13	
Random 16	0	98.81	92.74	73.56	17.1	0.95
" 18	0	99.32	95.39	84.74	15.2	1.4
" 19	0	99.48	96.40	88.10	14.4	2.0
" 24	0	99.87	98.88	95.24	11.4	5.5

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TABLE 2

ITU - ROME PROJECT 1963

Communication Lines	Number of Telephone Circuits	
	1968	1975
1 - Europe - North America	834	2100
2 - Europe - Maghreb	468	961
3 - North America - Latin America	261	675
4 - Europe - Africa	190	339
5 - North America - Far East	90	165
6 - North America - Africa	73	109
7 - North America - Australia	56	103
8 - Europe - Indian Peninsula	29	97
9 - Europe - Latin America	29	94
10 - Europe - Australia	31	75
11 - Latin America - South Africa	46	69
12 - South Asia - Far East	34	51
13 - Europe - Far East	27	46
14 - North America - Indian Peninsula	13	34

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TABLE 3

COVERAGE OF THE TRW/ITT SYSTEM OVER
MAIN COMMUNICATION LINES
(6-hour satellites: 2 × 6 and 2 × 8)

Communication Lines	Percentage of Time during which N Satellites are Visible					
	N = 1		N = 2		N = 3	
	2 x 6	2 x 8	2 x 6	2 x 8	2 x 6	2 x 8
Andover - Western Europe	100	100	100	100	77,01	100
Miami - Rio de Janeiro	90.84	98.67	9.94	35.34	0	0
Seattle - Tokyo	100	100	90.01	100	14.78	67,51
Western Europe - New Delhi	99.48	100	72.54	94.72	16.58	54,07
Seattle - Honolulu	100	100	77.85	97.57	18.78	53,93
Honolulu - Sidney	75.95	87.08	0.05	14.18	0	0

satellites had centered its attention since 1962 on the comparative merits, from the European viewpoint, of a phased system with an 8-hour equatorial orbit (altitude: 14,000 km) and on the stationary-orbit solution. The corresponding coverages are shown in Figs.1, 2, and 3.

It is obvious that the selection of a particular system is greatly influenced by the traffic it is able to ensure. The anticipation of international requirements, evaluated during the meeting of the ITU (International Telecommunication Union) at Rome in 1963, are compiled in Table 2. All communication lines are coverable by the communications satellites, except possibly the link between Europe and Maghreb.

To meet such requirements, the TRW/ITT proposed the following system:

circular polar orbit of a 6-hour period (altitude: 10,400 km);

two perpendicular orbital planes;

six or eight equidistant satellites per orbital plane (phased system).

The service obtainable with this system is shown in Table 3. However, even when using 16 satellites, the principal communication lines will suffer interruptions.

An improved version of the phased system has been developed by the National Center of Telecommunications Studies (C.N.E.T.) in France. The general layout [7] is as follows:

Twelve-hour circular orbit (altitude: 20,400 km).

Three orbital planes, inclined by 30° to the plane of the equator and staggered by 120° in the system of equatorial coordinates; each plane, with respect to the earth, occupies the place that had been occupied by the preceding plane, eight sidereal hours before.

Four (or five) satellites per orbit; these satellites are not equidis-

TABLE 4

COVERAGE OF THE C.N.E.T. SYSTEM OVER PRINCIPAL AND SECONDARY LINKS
(12-hour satellites: 3 × 4 and 3 × 5)

Communication Lines	Percentage of Time during which N Satellites are Visible					
	N = 1		N = 2		N = 3	
	3 x 4	3 x 5	3 x 4	3 x 5	3 x 4	3 x 5
Pleumeur-Bodou - Andover	100	100	100	100	28.6	86.97
Andover - Rio de Janeiro	100	100	100	100	71.66	91.65
Pleumeur-Bodou - Abidjan	100	100	100	100	100	100
Portland - Ibaraki	100	100	82.44	100	1.45	30.25
Pleumeur-Bodou - Bombay	100	100	64.16	88.43	0	12.88
Singapore - Ibaraki	100	100	100	100	52	98.6
Andover - Abidjan	100	100	100	100	59,7	97.5
Portland - Sidney	92.37	100	61.77	62.09	20.34	35.14
Bombay - Ibaraki	100	100	53.72	82.07	2.50	20.07
Pleumeur-Bodou - Rio de Janeiro	100	100	100	100	38.22	78.74
Sidney - Bombay	100	100	100	100	50.24	90.57

tributed but occupy a sector of 120°.

The value of the longitude of the ascending node of the first satellite, on passing over the equator through a plane taken as reference, is 160° East.

The relative position of the three groups of satellites, set at a given instant, can be conceived as a type of three-blade propeller where each blade, carrying four (or five) satellites, is formed by a plane sector of 120° angular aperture, inclined by 60° to the axis of rotation of the earth.

The coverage offered by the system is shown in Table 4.

The line Europe - Maghreb has not been taken into consideration; for the other communication lines, it is obvious that the service is much superior to a system with two polar planes.

In the case of stationary satellites, the evaluation of coverage is very simple and depends only on the selection of the position of each individual satellite above the equator. Between two points on the globe, if communication is possible, this coverage will be permanent. In Figs.2 and 3, the positions were, respectively, 15° Long.W and 65° Long.E, which are the most interesting for Europe.

EARLY BIRD, launched on April 6, 1965, was positioned at about 30° Long.W and primarily takes care of the connection between Europe and the USA.

This satellite provides for the following:

240 bilateral telephone channels or

1 bilateral television link

which operate in combination with the four underseas cables installed, which total 350 two-way telephone channels but do not permit television transmission.

It should be mentioned that the satellites of the worldwide network of the COMSAT Co., to be placed into orbit at the end of 1967, should have a capacity of more than one thousand two-way channels, to take care of the traffic predicted for the years 1968 to 1975. /9

The Russians follow an entirely different policy. Their first communications satellite, the MOLNYA I, launched on April 23, 1965 moves on an eccentric elliptical orbit, with an apogee of 39,957 km in the Northern Hemisphere and a perigee of 548 km. The period is close to a 12-hour orbit. The orbital plane is inclined by about 65° to the equator.

The interesting aspects of this type of configuration for telecommunications had been mentioned already in 1960 at the Congress of the International Federation of Astronautics in Stockholm, by two British scientists: W.F.Hilton and C.S.Dauncey. They demonstrated primarily (Fig.4) that a 12-hour orbit of the eccentric type would permit a useful service of 20 hrs out of every 24 hrs. In addition, if the inclination α of the orbital plane with respect to the equator satisfies the condition

$$5 \cos^2 \alpha - 1 = 0 \qquad \alpha = 63.40^{\circ}$$

the major axis of the ellipse will be stationary in the orbital plane and the latitude of the apogee will remain constant.

This property is specifically advantageous if it is a question of servicing one Hemisphere (for example the Northern Hemisphere; Fig.5) by a very restricted number of satellites that are relatively easy to launch. Figure 6 shows the trace, on earth, of the MOLNYA I trajectory of April 28, 1965.

In all, there are 15 hrs of mutual visibility per day between Moscow and Vladivostok. The satellite is attitude-stabilized and is equipped for transmitting television images of the Soviet standard, over the range of 980 mc.

Today, after fine corrections of the orbit, the period is 12 hrs to within 1/3 min, and the inclination to the plane of the equator is 65.35°.

The orbit precesses toward the West at a rate of approximately 1.25° per day.

The ascending nodes on July 1 were, respectively, at

15.45° Long.W, at $0^h\ 7^m$ GMT;

163.91° Long.E, at $12^h\ 8^m$ GMT.

The apogee is at 39,592 km and the perigee at 587 km.

CONCEPTIONS OF SATELLITES /10

We showed that, in the USA, two systems are still competitive, namely, medium-altitude phased satellites and geostationary satellites. To bring out their differing characteristics, we will briefly review the basic techniques realized in each case, starting with the launching procedures.

1. Insertion into Orbit

EARLY BIRD, launched April 6, 1965, represents an excellent typical example (Fig.7). The launching took place from Cape Kennedy by an improved more powerful DELTA rocket booster (TAD) toward the East at an inclination of 28.7°, inserted into a low orbit. On passing over the equator, the third stage of the booster inserted the satellite, which first had been given a spin rotation, into a highly eccentric transfer orbit whose apogee was at the altitude of the synchronous orbit (36,000 km); at the same time, the inclination was corrected to 18.2°. The satellite, at this moment, separated from the carrier rocket. Thus, the entire work of the booster is performed at low altitude.

On the fourth apogee, an acceleration is produced by the perhydrol (H_2O_2)

rocket, for slightly modifying the perigee (Fig.8).

On passing over the equator during the sixth apogee and after an accurate adjustment of the satellite attitude, the perigee-lifting burn goes on. Because of the vectorial composition of the thrust and of the velocity, the inclination of the orbital plane is completely corrected while still proceeding in a circular orbit (Fig.9). At this distance from the earth, equal to about six earth radii, the acceleration of gravity is reduced so that the thrust required of the apogee rocket is relatively moderate. The increase in velocity obtained is about 1400 m/sec for a variation in mass of the satellite from 67.5 kg before firing of the rockets to 40 kg, which is due to the emptied tank of the apogee rocket.

After these operations, the characteristics of the resultant orbit will be quite close to the desired values. Fine corrections are made over the following days, using the perhydrol command device, so as to obtain rigorous synchronism with the earth and so as to set the axis of gyroscopic rotation perpendicular to the plane of the orbit. This is done to within $\frac{1}{2}$ degree, the residual inclination of the orbital plane itself being 0.0085°. The maneuvers of the perhydrol command device are compiled in Table 5.

The exploitation of EARLY BIRD since its launching has made it possible to accumulate a certain number of observational data of various types. /11

The residual drift, after the end of the positioning maneuvers in orbit, was $5/100^\circ$ per day. The satellite was allowed to drift up to the limit of visibility of the Raisting station (Germany), i.e., 37.5° Long.W. Around July 20, the drift will have to be stopped and its direction will have to be changed. The drifting will then continue toward East up to 25° Long.W where the satellite will stop and automatically reverse its direction (25° W is still within the range of good visibility from Andover). The next orbit correction will not be

made before February 1966. Conversely, the inclination of the orbit to the equator, which was almost zero at the beginning, will progress further under the

TABLE 5

EARLY BIRD, PERHYDROL COMMAND DEVICE

Number of orientation maneuvers	5
Number of velocity maneuvers	4
Number of elementary actions of the dampers	2,969
Initial charge of propergolic fuel	4.6 kg
Total initial velocity increment	200 m/sec
Remaining propergolic fuel	2 kg
Fuel requirements for orbital stabilization	45 gm/year

effect of the gravitational attraction of both moon and sun, with a maximum variation as high as 1° per year. The present inclination is about $1/3^{\circ}$. The permanent correction of this inclination will use up the remainder of the propergolic fuel reserve, in about one year's time. It will be recalled that the inclination produces an apparent motion in the form of a figure eight about the equatorial position, with an amplitude equal to the inclination. The four earth stations, presently in connection and presenting beams of $15/100^{\circ}$ to $20/100^{\circ}$ aperture, have automatic tracking and pointing systems and thus have no difficulty in tracking the evolutions of the satellite.

Another observation concerned the interference with the moon and sun, i.e., the periods of alignment of a given satellite ground station with one of these two celestial bodies. At these times, the lobe of the ground-station antenna, of the cold antenna type, is aimed at an intense noise source which practically interrupts all transmission. An interference of 6 min with the moon has been

observed in July. The next interference with the sun will take place in December and will repeat twice a year.

It is obvious that this command system for position and attitude, which /12 has profited from the experience gained with the SYNCOM II and III, apparently has reached a high degree of operational reliability.

In the HS 304 version, which is laid out for 1000 telephone circuits and has an orbital mass of 150 kg, a multiple launching - up to four satellites - in a cluster, from a single Atlas-Agena type rocket, has been scheduled.

Such a multiple launch is of considerable advantage since the cost of placing a satellite into orbit with respect to the unit mass in orbit, decreases with increasing power of the launch vehicle.

A typical example of the launching of a cluster satellite is that proposed by TRW/ITT for the 2 × 6 or 2 × 8 phased system in a 6-hour orbit. These satellites have a weight of about 200 kg (including the apogee rocket) and are launched in pairs by a "Thrust Augmented Thor-Simplified Ascent Agena" (TAT-SAA). Figure 10 gives the sequence of insertion into orbit. The combustion cutoff of the last stage takes place at an altitude of 150 km, inserting the pair of satellites into an elliptical transfer orbit. The satellites, placed into gyroscopic rotation, are started at 2-sec intervals by the action of springs. At the apogee of the transfer orbit, the apogee rocket of each satellite is cut in and produces an intermediary orbit, close to the final circular orbit. One after the other, the satellites are taken over by telemetry commands. Due to the combined action of auxiliary rockets with perhydrol and compressed nitrogen, the following is obtained:

setting the satellite in position;

adjustment of the orbital period;

reduction of the eccentricity.

This latter correction is specifically necessary for a satellite stabilized by gravity gradient, which is exactly the case here. Then, the spin motion of the satellite is arrested, the stabilization surfaces by gravity gradient are deployed (arm of about 10 m), and the damping unit is cut in so as to reduce the oscillations about the equilibrium position. After these various operations are completed, which requires about 2 - 3 weeks, no other velocity correction is applied during the entire life of the satellite, which naturally is especially economical from the viewpoint of reliability. The mutual residual drift of the satellites, according to present estimates, will remain below 1° per year.

2. Attitude Stabilization /13

The radioelectric links consume a minimum of on-board power since the antennas are constantly pointed at the earth, with the radiation pattern adapted to the altitude:

cone of 45° at 10,400 km;

cone of 17.25° at 36,000 km.

Thus, an attitude stability of the satellite, relative to the local vertical, is required which has an accuracy better than 1/10 of the beam aperture.

Stabilization by gyroscopic rotation of the entire satellite unit, about an axis perpendicular to the plane of the orbit, is an especially simple and efficient method. This method of spin stabilization has been used on several satellites, both of the scientific and meteorological types, and specifically in the SYNCOM series. The velocity is of the order of 100 - 150 rpm and, since the deceleration due to Foucault currents or to the magnetic hysteresis is quite low, the velocity need not be supported. If the orbit is either polar or equa-

torial, the spin axis will remain perpendicular to the orbital plane; conversely, if the orbit is inclined relative to the equator, the orbital plane will precess and periodic corrections must be applied to the spin axis. In addition, the nutations of the axis about its mean position must be corrected. This is done on EARLY BIRD by a passive damper, consisting of a glass tube partially filled with mercury and aligned parallel to the axis. The motion of the mercury in the tube dissipates the oscillation energy of the system.

Another, quite important, advantage of stabilization by rotation is that of facilitating the temperature regulation problems, due to the variable exposure of the outside satellite surfaces to the sun.

In the first generation of SYNCOM satellites (SYNCOM II, SYNCOM III, and EARLY BIRD) the type of antenna used in spin stabilization was only directional in the plane parallel to the axis (polar plane) and omnidirectional in the perpendicular plane. To benefit from the maximum gain possible, an antenna with a conical radiated beam must be used together with a counterrotating device, which directs the beam at each instant toward the earth.

A mechanical solution is well within the range of possibilities, but has not yet been developed. For the new generation of SYNCOM satellites, the Hughes Aircraft Co. has developed an antenna unit with electronic counterrotation.

This array consists of 16 radiating elements, distributed over a circle /14 centered on the gyroscopic axis (Fig.11). If, during their rotation, each of the N elements is fed by a phase such that

$$\Phi_n = \frac{2\pi R}{\lambda} \cos \theta_n$$

then the wave front radiated by the array will be a plane perpendicular to the axis $\theta = 0$, and the direction of the radiation lobe will remain stationary de-

spite the rotation of the individual elements. The phase variations are applied by means of electronic-command ferrites (Fig.12). The command signals, which allow for the rotation of the satellite, are obtained from a reference datum delivered by a solar sensor. An on-board clock allows for the variation in the apparent angle of both sun and earth. In addition, the telemetry and telecommand links will permit possible resettings.

Each element of the circular array is constituted by an elementary linear array, so that the radiated beam is directional in the two principal planes. The experimental model produces a beam which is practically a body of revolution of 20° aperture, at a gain above 15 decibels and a bandwidth of the order of 200 mc. This system, which has not yet been flight-tested, requires highly complex electronic on-board circuitry. It is conceivable that the elaboration of the dephasing signals can be done, in part, on the ground with retransmission over the remote control and telemetry channels.

The TRW solution of attitude stabilization differs from the above. Here, a mechanical stabilization of the satellite body by gravity gradient is used. In such a system, as soon as the deployment operations are terminated, no electronic device is operated and no power is drained from the on-board power unit. The stabilization, effected with respect to the local vertical, is specifically well suited for beaming a telecommunications antenna toward the ground.

The general principle is, briefly, as follows:

A satellite, traveling in the field of terrestrial gravitation, is subject to a restoring moment which tends to make the axis, about which its moment of inertia has a minimum, to coincide with the local vertical. To make use of this property under the optimum conditions, it is necessary to give the satellite, at least after its insertion into orbit, a structure such that one of the principal

moments of inertia will be low with respect to the other two. However, this is not sufficient in itself to ensure stabilization. The satellite, subjected only to the restoring moment resulting from the gravity gradient will oscillate indefinitely about the local vertical. Therefore, it is necessary to install a damper for these oscillations. This is usually an auxiliary body or "anchor" with respect to which the satellite will be in motion when oscillating about the vertical, with the coupling introducing viscous friction for absorbing the oscillation energy. /15

In practical use, to impart the wanted form to an ellipsoid of inertia, exterior masses, coupled with the satellite and located at a considerable distance from its inertia center (several meters or more), must be added. Since such distances cannot be accommodated on board the vehicle, it is necessary to deploy these masses after insertion into orbit. For this, telescope rods are used, which were developed by the Canadian De Haviland Aircraft Corp. These rods consist of a beryllium bronze strip which is originally wound on a tambour and, on developing, forms a tubular rod. Another possible configuration, taken from studies made at the French Subsidiary of Thomson-Houston is that shown in Fig.13. So as to clear the radiation cone of the antennas, the rods coupled with the satellite are arranged in X form. The axis of the anchor is separate from the principal axes of the satellite, so as to damp the motion about three axes. The damper itself can be either of the Foucault-current type or of the magnetic hysteresis type.

Extending of the rods requires some precautions. To ensure proper insertion into orbit and positioning in orbit by means of auxiliary rockets and jets, the satellite is prestabilized by rotation. When stopping this rotation, the kinetic energy, which now is detrimental, must be dissipated. After this has

been accomplished (either by a gas jet and a free reaction sphere or by yo-yo), the extending of the rods permits acquiring of the vertical, although with a certain ambiguity relative to the high and low direction of the satellite. For this reason, the satellite is equipped with twin communications antennas, with the antennas of the operative side being connected by remote control after acquisition of the vertical.

In view of numerous perturbing phenomena such as eccentricity of the orbit, solar radiation pressure, Foucault currents, residual magnetic moment under the effect of the terrestrial magnetic field, spherical harmonics of the earth potential produced by the oblateness of the earth, residual aerodynamic drag, deformation of the rods by insolation, etc., it is difficult to obtain a stability accuracy of close to one degree or even of several degrees. However, this might be sufficient for pointing the communications antennas. The condition of a rigorously circular orbit is particularly necessary, which excludes the stabilization by gravity gradient on eccentric orbits. Temperature regulation /16
which has a great influence on the operating reliability of the various electronic elements is quite difficult to obtain, since certain regions of the satellite surface are exposed to solar radiation (6000° K) for long periods of time while other surfaces face the intersidereal cold (4° K).

It is difficult to render the system compatible with the position commands, as they are applied to a stationary satellite, in view of the fact that the rods would have to be especially long in this case.

At present, the gravity gradient device has been tested in the United States in orbits of about 500 km. The use of such devices in orbits of 10,000 km and higher is part of the ATS (Advanced Technology Satellites) program of NASA.

3. Electric Power Supply; Solar Cells

The only practically useful electric power source, at the present state of the art, are silicon solar cells.

The power supply of the on-board equipment is from 27 w for EARLY BIRD to 50 - 70 w for a satellite with 1000 telephone circuits.

In view of the progressive degradation of these cells under the bombardment by various particles, it is necessary not only to devise a protective casing for these cells but also to greatly overdimension the on-board power station if life-times of the order of 5 -10 years are to be ensured. Depending on the altitude of the satellite, the environmental conditions differ extensively.

The Van Allen radiation belts are shown schematically in Fig.14. The particles trapped in the inner belt are mainly protons ranging in energy from 40 to 100 Mev. The outer belt comprises predominantly electrons with an energy of the order of 1 Mev. Relatively accurate data on the distribution of protons and electrons have recently been collected by "EXPLORER 15". In addition to these distributions, based on the earth's magnetic field, allowance must also be made for the proton clouds originating from solar eruptions; their energy ranges between 10 and 100 Mev at the maximum of solar activity. These latter penetrate almost to the region of the first Van Allen belt.

Figure 14 indicates that the 6-hour orbit is the most hazardous; conversely, the 24-hour orbit proceeds within a specifically convenient environment. /17

Because of the data collected by scientific satellites and further perfected by experimental degradation measurements made specifically by TELESTAR I, SYNCOM II, and SYNCOM III, it has become possible to determine the necessary protective shielding to be provided for solar cells and to define their timewise evolution. The solid curves in Fig.15, corresponding to a quartz coating of

0.3 mm thickness, differ greatly for the three selected orbits, namely, 6-hour, 12-hour, and 24-hour. The broken curves, corresponding to the same orbits and referring to a protective layer of 0.8 mm, are much more clustered. Obviously, for lifetimes of less than five years, thicknesses of

0.3 mm for a 24-hour orbit and

0.8 mm for a 6-hour orbit

will give equivalent degradations. Beyond five years, the protective layer of the 6-hour satellite would have to be further reinforced.

4. Telecommunications Equipment

The satellite is expected to cover more or less the same surface of the globe, no matter what the altitudes within the 6000 and 36,000 km range might be. At equal traffic capacity and at an antenna radiation pattern well adapted to the solid cone to be serviced, the energy received or transmitted by the satellite transponder is independent of the altitude. Thus, the characteristics of the communications equipment do not vary.

It should be noted that, in an elliptical orbit, the aperture of the antenna beam must proceed along the trajectory so as to preserve the above-mentioned optimum yield which, speaking from a technical viewpoint, is not easy.

On EARLY BIRD, the transmission subsystems are installed in duplicate. The incident signals, coming from the ground stations within the range of 6 Gc, are received by an antenna with toric beam and 4 db gain, centered on the spin axis and linked to two continuous-wave receivers which are slightly staggered in frequency. Each receiver is equipped with a mixer, a local oscillator, and an IF amplifier of 25 mc, provided with a limiter. At the output of the two receivers, the signals are transposed in frequency within the range of 4 Gc and are used

for feeding, in parallel across a hybrid circuit, two traveling-wave tubes of 6 w output each. One or the other of these tubes can be placed into service by remote control. Each accepts the entire frequency band of the two receivers, including the guard band. The transmission antenna is a slotted linear array /18 with 9 db gain, aligned with the axis of rotation. The radiation pattern, of toroidal form, has an aperture of 10° in a plane passing through the axis, i.e., in a polar plane. The vertex in this plane is inclined by 7°, so as to favor the Northern Hemisphere.

The overall characteristics of EARLY BIRD are compiled in Table 6.

The general trend of development for the new generation of satellites is as follows:

- Simplify the circuit diagram by operating a direct ultrahigh frequency amplification at the receiving end, followed by simple frequency transposition.
- Increase the bandwidth to 200 mc or wider, so as to increase the traffic capacity (1000 - 1200 telephone circuits).
- Generate a linear characteristic, yielding greater flexibility of use for the multiple access techniques to be developed in the future.

This is illustrated in the diagram of Fig.16, proposed by TRW/ITT.

The receiving and transmitting antennas are in duplicate, because of the ambiguity of acquiring the vertical of the satellite by gravity gradient, as mentioned above. The 6 Gc signals, coming from the ground stations, are worked up by a tunnel-diode amplifier with a low input noise factor (6 db). Here, a single frequency transposition from 6 to 4 Gc is effected. Finally, amplification is obtained by two traveling-wave tubes connected in cascade, whose output power is 4 w. In the Hughes Aircraft variant, the frequency conversion is

followed by a tunnel-diode amplification, feeding a high-gain traveling-wave tube of 6 w output.

TABLE 6 /19

HS 303 EARLY BIRD

PRINCIPAL CHARACTERISTICS

Structure

Cylindrical; 70 cm diameter and 60 cm height.

Mass

On launching, 67.5 kg; in orbit, 40 kg.

Apogee Rocket

Solid propergolic fuel rocket, model SYNCOM developed by Jet Propulsion Laboratory;
Propergolic fuels, 27.5 kg; velocity increment, 1400 m/sec.

Command Device

Two command subunits with perhydrolic fuel (H_2O_2), each with axial and radial jet;
Total velocity increment, 200 m/sec.

Electric Power Supply

45 w, solar n-p junction silicon cells;
Two cadmium-nickel batteries (1.5 amp-hr).

Remote Control

Redundant remote control with 12 UHF channels.

Telemetry

Twelve channels on each of two SHF beacons and each of two VHF transmitters, 136 mc, 1.8 w.

Telecommunications Equipment

Two MF amplifier receivers, 25 mc bandwidth;
240 two-way telephone channels with two carrier waves;
Two transmitting TOP of 6 w, one of which is used as back-up unit;
Antenna gain, 4 db on receiving and 9 db on transmitting.

In this type of solution, the number of components is extremely reduced, specifically those that are sensitive to penetrating particle bombardment. The expected life of these traveling-wave tubes exceeds 10 yrs.

A comparison of the various present-day satellite conceptions induces the following general conclusions. From the Russian side, the approach to the problem is ingenious but uses relatively frustrated solutions without attempt at refinement; economical orbit, no passive stabilization, no optimizing of the transmission system.

On the American side, one school is in favor of the severe environment of medium-altitude orbits and, for ensuring reliability, proposes a reduction in the number of elements participating in the operative function.

Another school advocates the favorable environmental conditions of the synchronous altitude for ensuring long life of relatively complex devices, each of which - however - has been thoroughly tested as to function and reliability.

EUROPEAN POSSIBILITIES /20

A critical study of the research and development in progress, specifically in the United States, permits a better orientation, on the European plane, of the various projected communications satellite programs. It is certain that the disciplines, reviewed above, are within the capacities of the technical and industrial potential of France, who already is an active member in the European Space Research Organization (CERS-ESRO) and in the European Launch Development Organization (CECLES-ELDO).

The guide lines to be used are greatly influenced by the potentialities of the available launch vehicles, within the space of several years.

The projected estimates by CECLES-ELDO which, until now, has tested the

principal elements of the launcher of the initial program, are as follows:

By making use of the apogee rocket (configuration ELDO AS) for apogee burn, i.e., using the sequence of

cut-in on the parking orbit,

elliptic transfer orbit,

insertion into circular orbit by apogee rocket incorporated into the satellite,

the following is obtained in polar orbit, firing the WOOMERA toward the North:

6-hour orbit, payload: 150 kg + apogee rocket pod;

8-hour orbit, payload: 100 kg + apogee rocket pod.

The consumption of propergolic fuel by the apogee rocket was assumed as 80 - 100 kg.

An improvement in performance can be obtained by using an equatorial base. The Guiana site, under French management within the frame of her national program and located within the satellite range, is among the possibilities considered by ELDO, one of the most promising.

Equatorial launchings toward the East under the same conditions as above, will permit the following:

8-hour orbit, payload: 175 kg;

12-hour orbit, payload: 100 - 110 kg.

The first satellite of the AS type should be launched during the first Quarter of 1969*.

The second phase of the ELDO program, known as ELDO B, should permit the production of operational launch vehicles in 1972 - 1973, with the following

* If the decision to continue the projected program is taken by the participating countries, the latest date will be the beginning of 1966.

configuration:

first stage, BLUE STREAK;

second stage, with cryogenic propergolic fuels;

apogee rocket, installed on board the satellite.

Launching from Guiana should permit to insert into a stationary orbit /21

250 - 350 kg payload

which corresponds to a large communications satellite, or else permit multiple orbiting of a pair of medium-size satellites, similar to the 1200-telephone circuit satellites developed by COMSAT.

The effort made in technical and technological developments in the various European countries, which should permit their mastering of the launching of communications satellites, is quite considerable. It must be remembered that, simultaneously, further progress must be made in the adaptation of telecommunications to the novel possibilities offered by satellites, such as the problems of multiple access. In these particular fields, the European support will suffer no handicap.

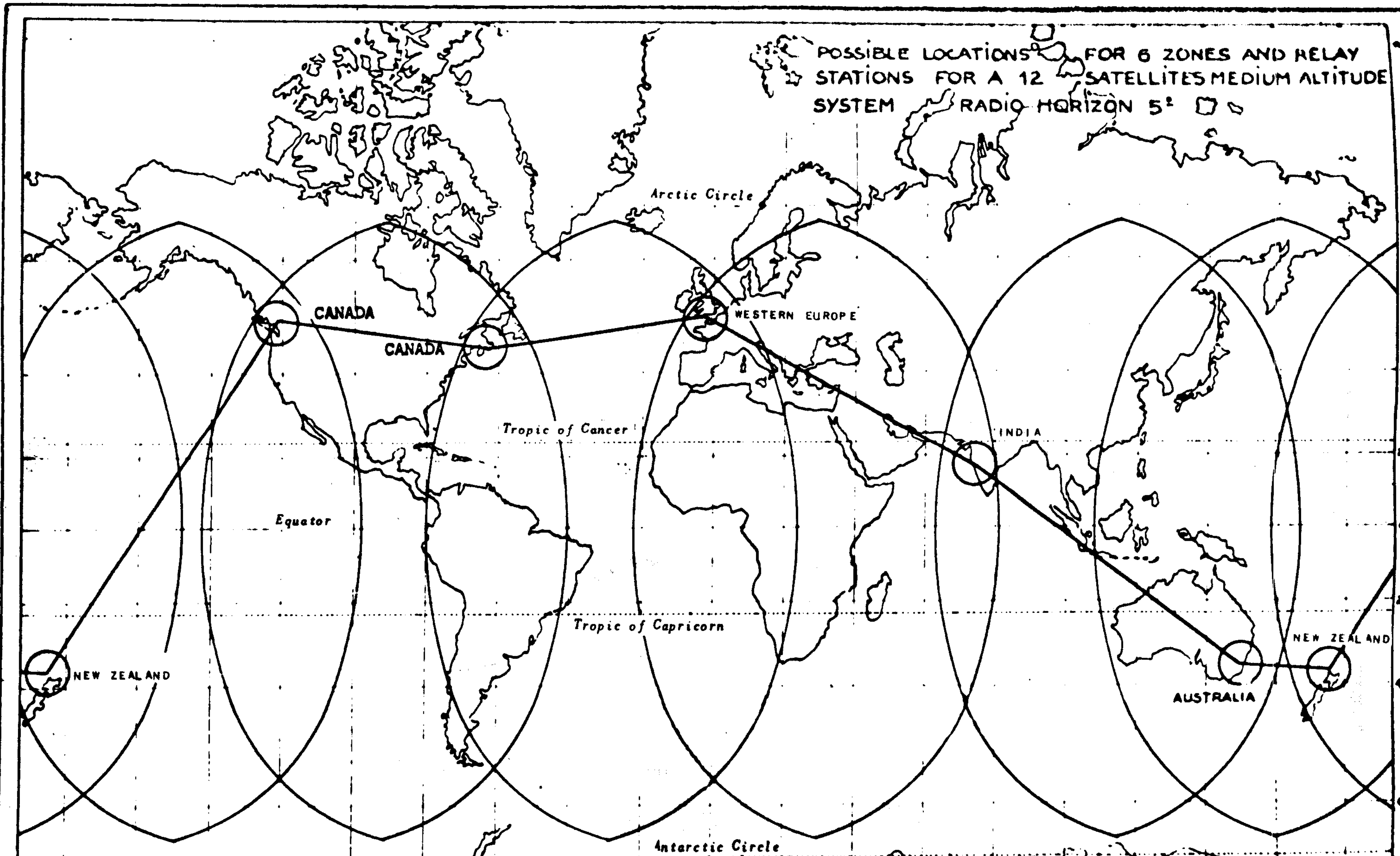

POSSIBLE LOCATIONS FOR 6 ZONES AND RELAY STATIONS FOR A 12 SATELLITES MEDIUM ALTITUDE SYSTEM RADIO HORIZON 5°
CANADA
CANADA
WESTERN EUROPE
INDIA
AUSTRALIA
NEW ZEALAND
NEW ZEALAND
Arctic Circle
Tropic of Cancer
Equator
Tropic of Capricorn
Antarctic Circle
180° Longitude 160° West 140° 120° 100° 80° 60° 40° 20° Meridian of 0° Greenwich 20° 40° 60° 80° 100° 120° 140° Longitude 160° East 180°

FIG: 1

/22

/23

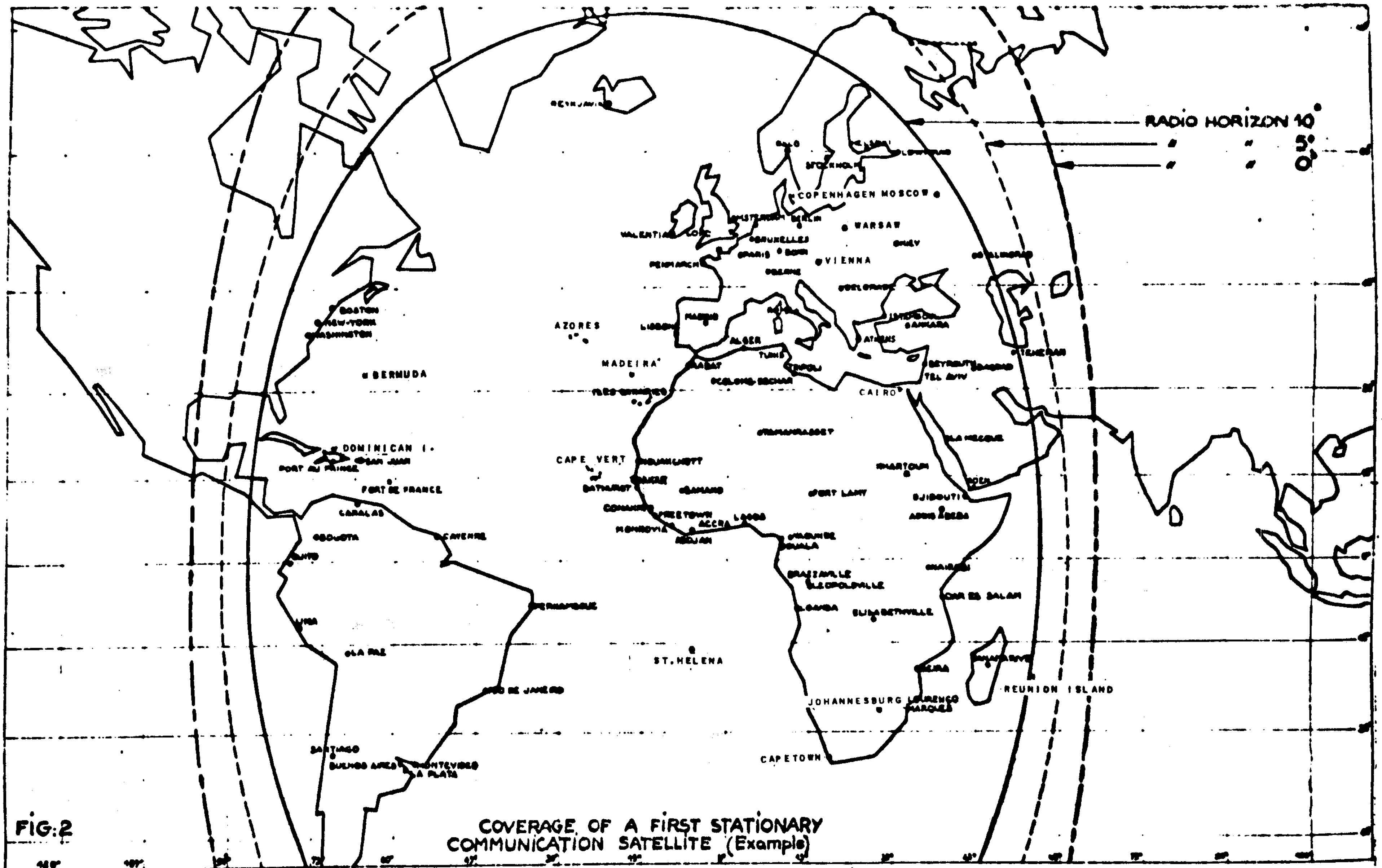


FIG:2 COVERAGE OF A FIRST STATIONARY COMMUNICATION SATELLITE (Example)

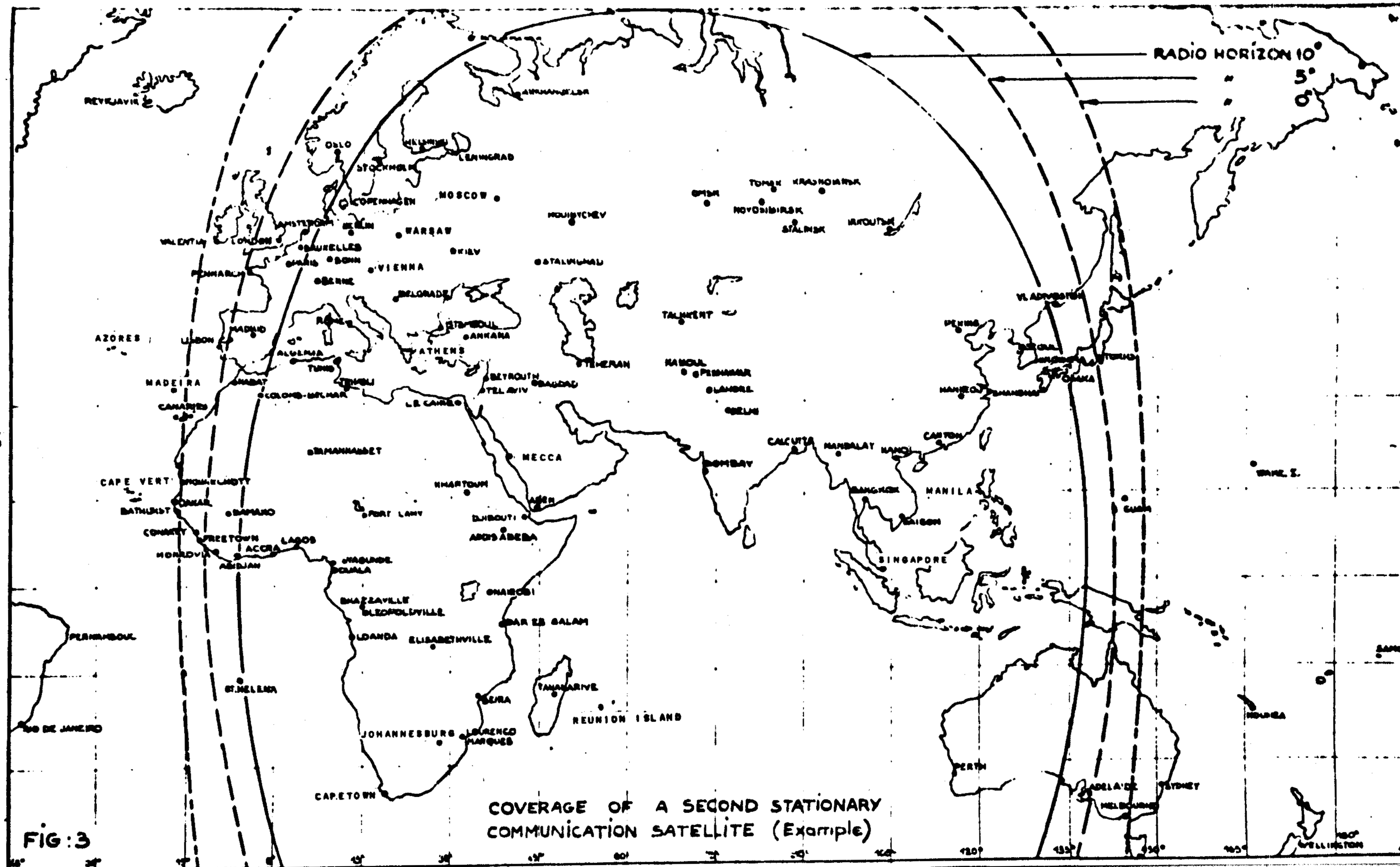
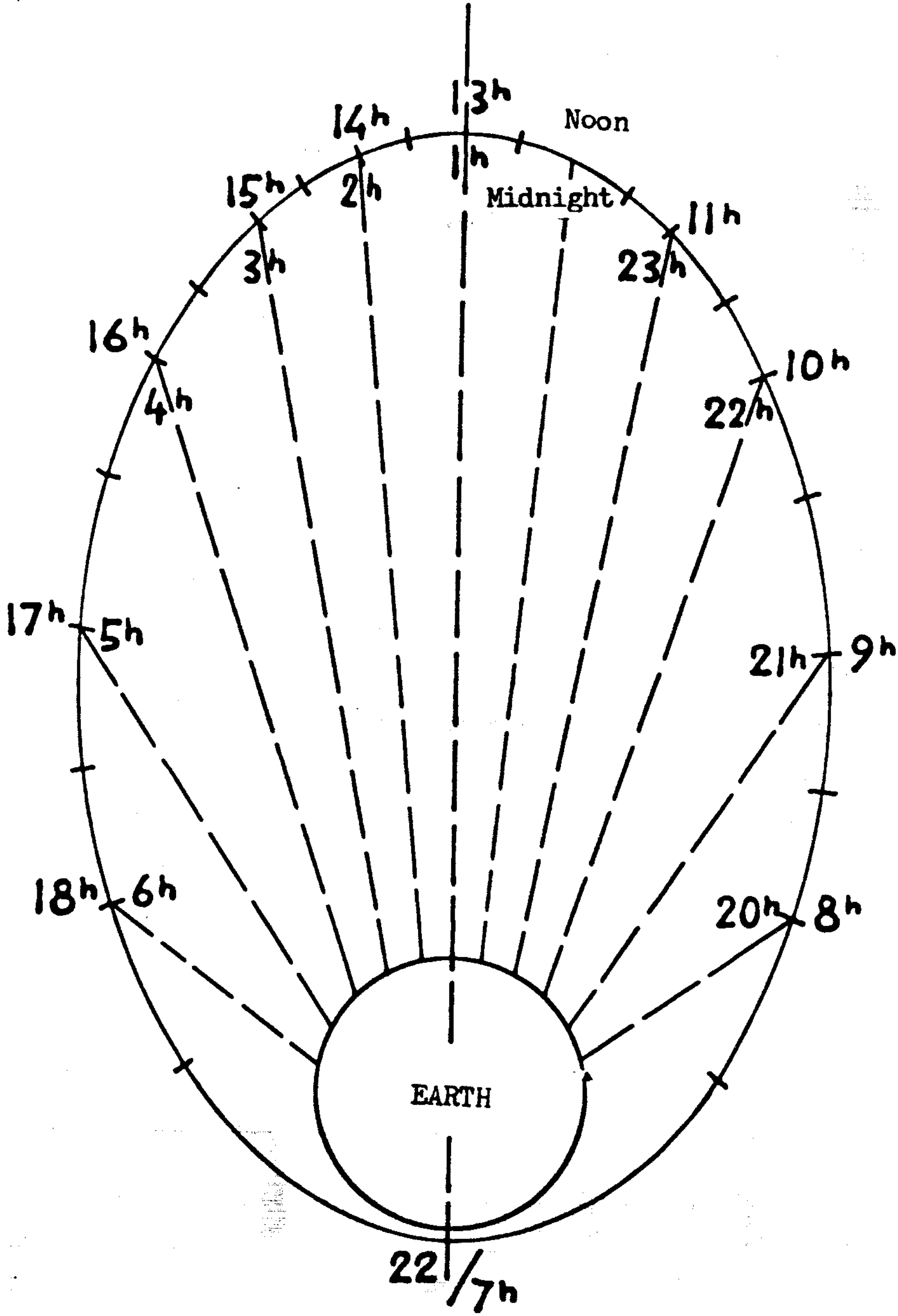


FIG: 3

COVERAGE OF A SECOND STATIONARY COMMUNICATION SATELLITE (Example)

124


13h
Noon
14h
1h
15h
2h
Midnight
11h
3h
23h
16h
10h
4h
22h
17h
5h
21h
9h
18h
6h
20h
8h
EARTH
22
7h

/25

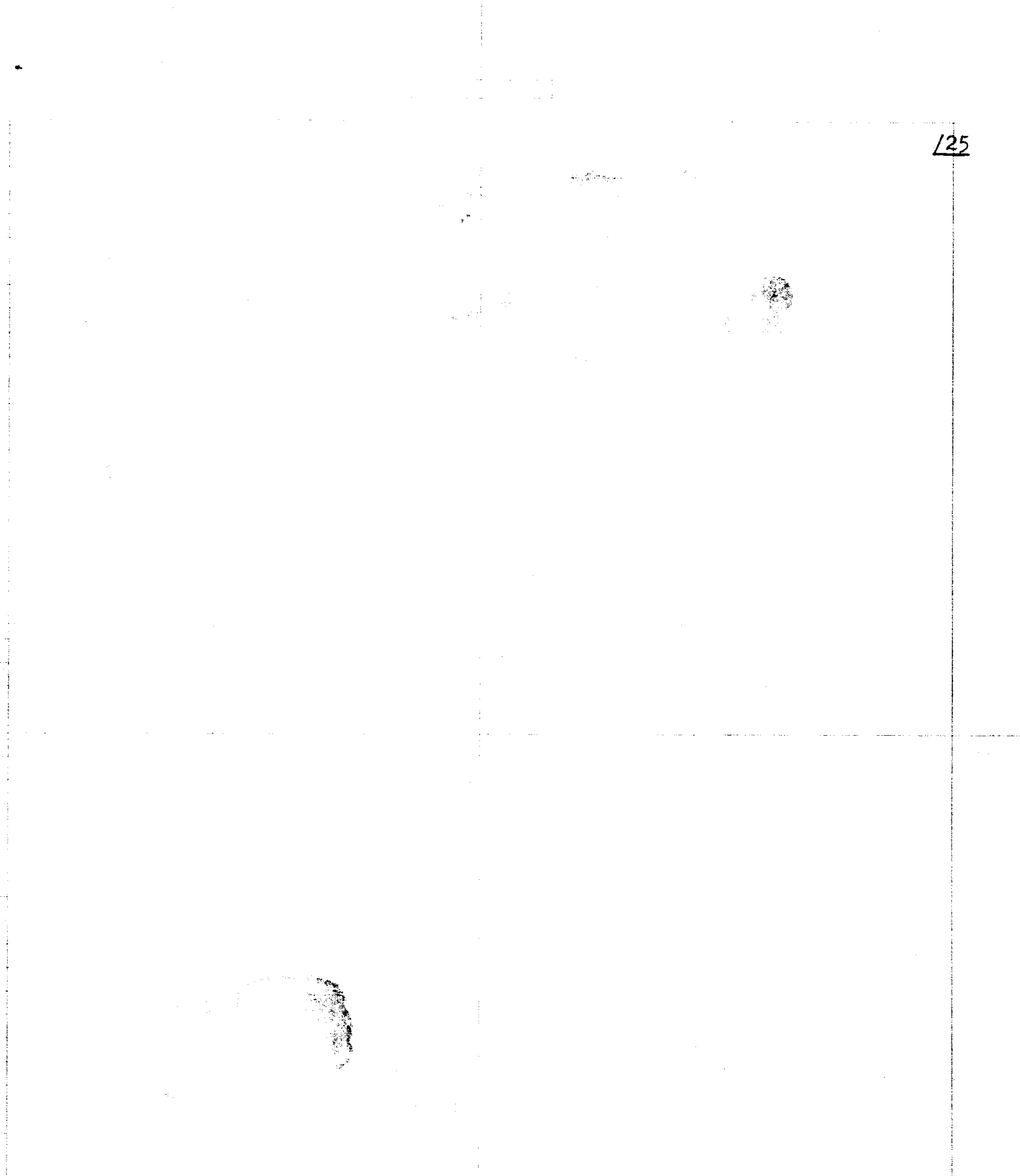
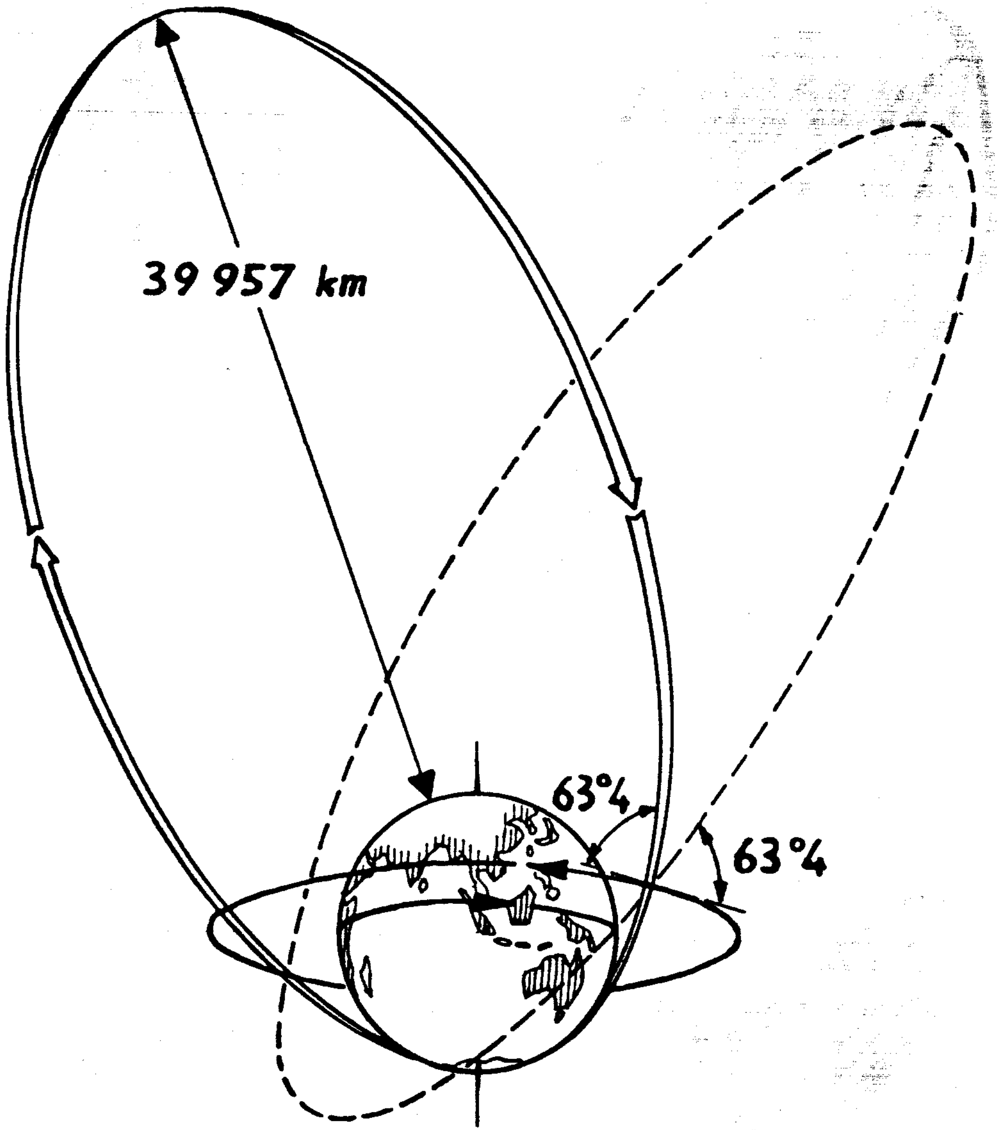
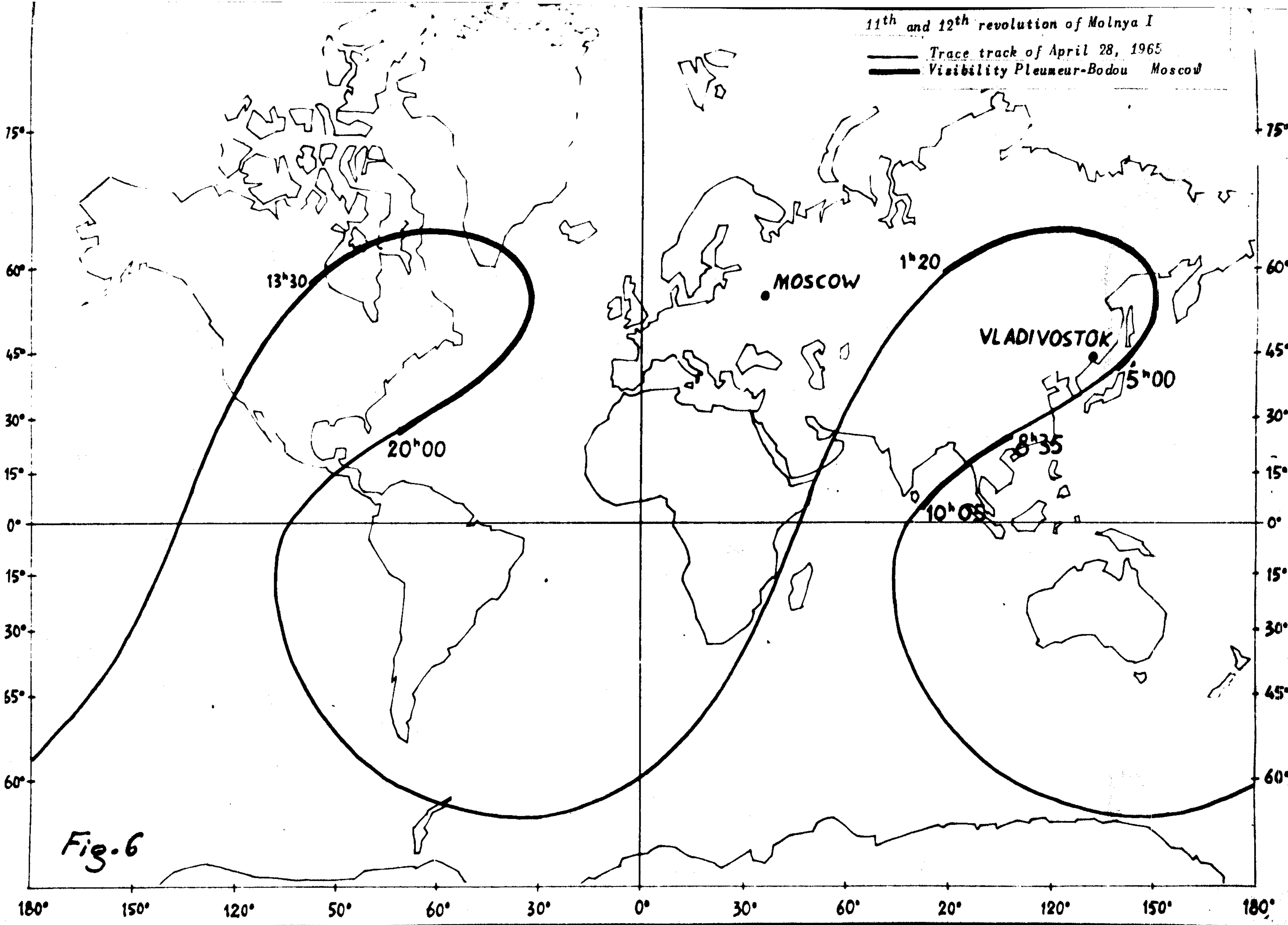


Fig.4 12-Hour Eccentric Orbit


39 957 km
63°4
63°4

/26

Fig.5 Orbit of MOLNYA I



11th and 12th revolution of Molnya I
Trace track of April 28, 1965
Visibility Pleumeur-Bodou Moscow
MOSCOW
VLADIVOSTOK
13h30
20h00
1h20
5h00
8h35
10h05
75°
60°
45°
30°
15°
0°
15°
30°
65°
60°
180°
150°
120°
50°
60°
30°
0°
30°
60°
20°
120°
150°
180°

Fig. 6

27

32

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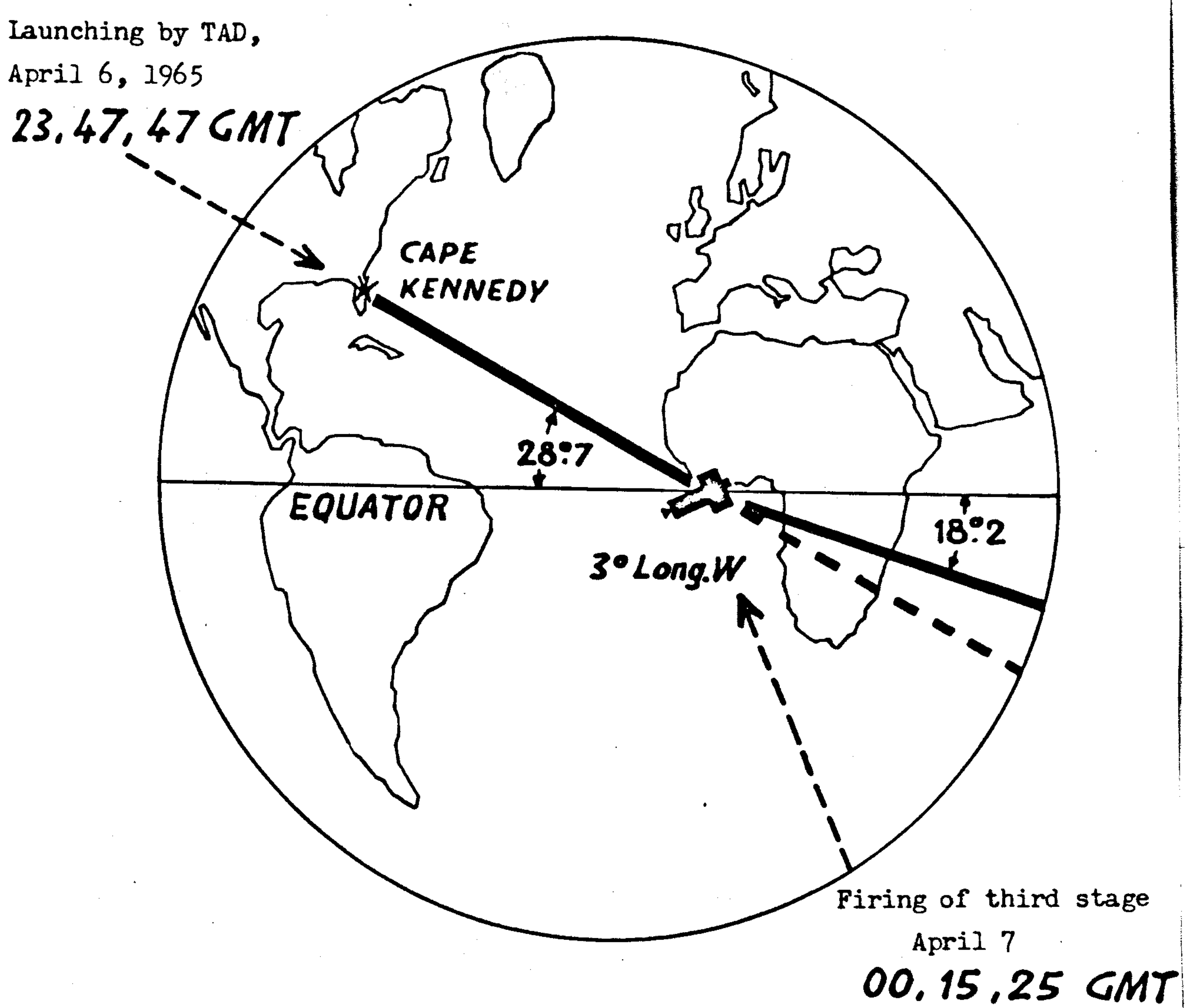

Fig.7 EARLY BIRD

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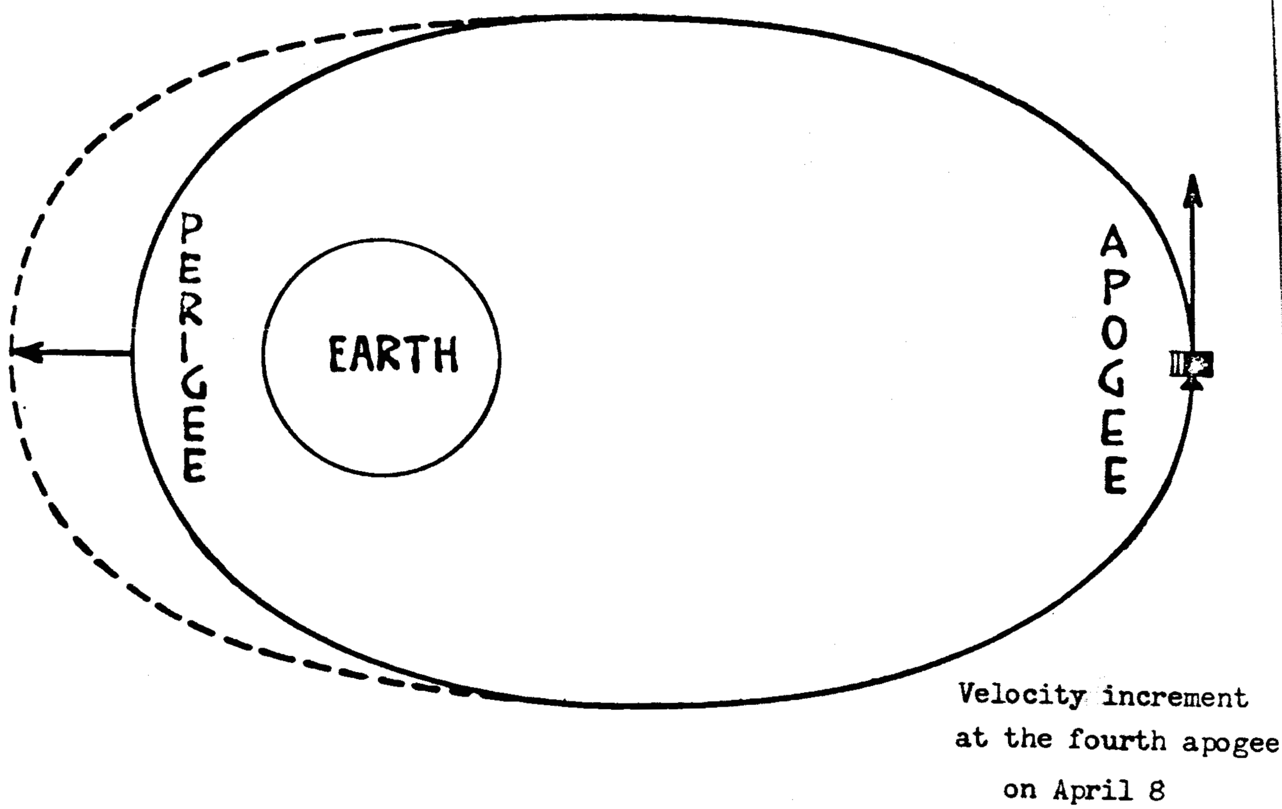


Fig.8 EARLY BIRD
Maneuver by perhydrolic fuel rocket

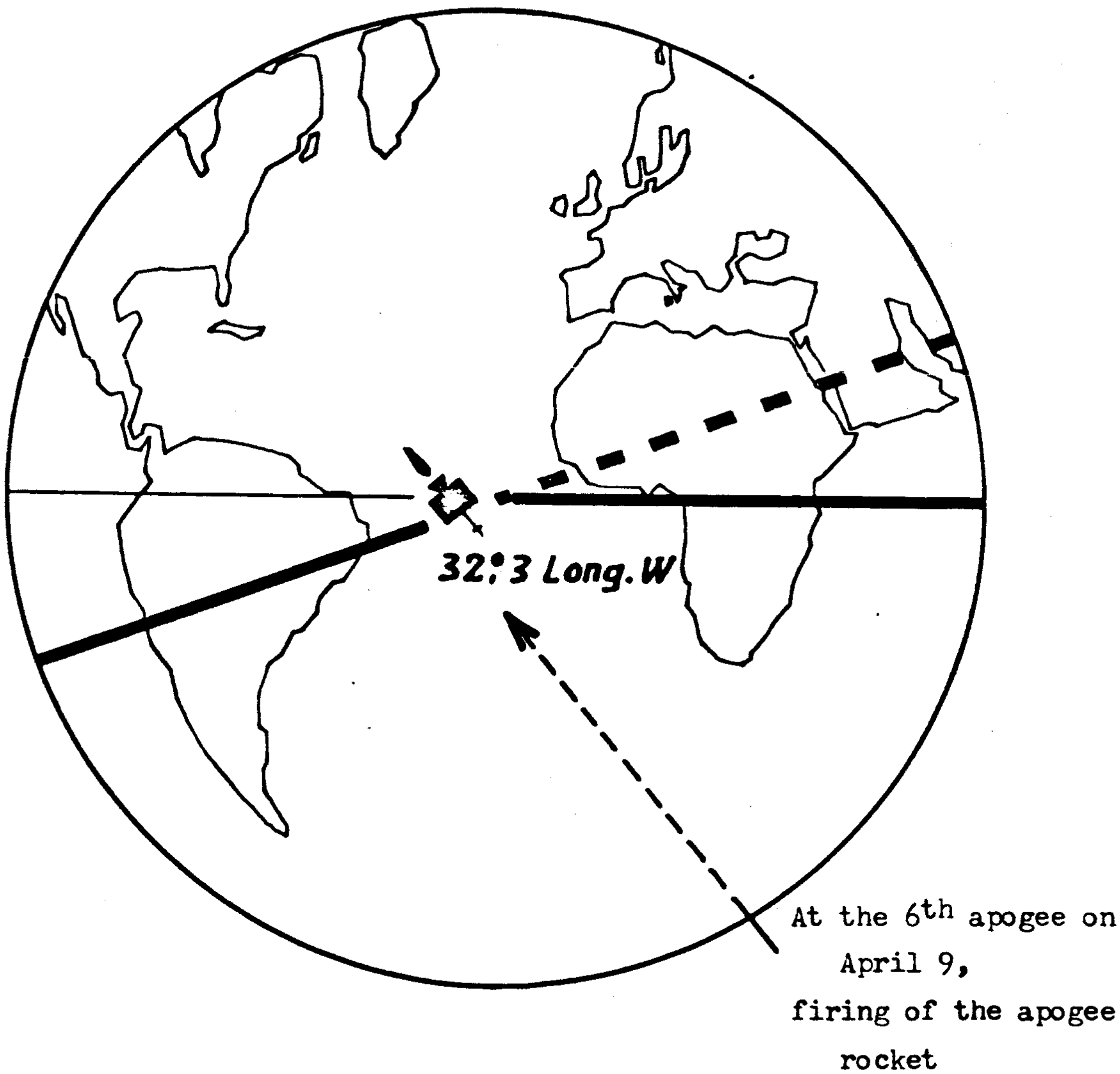
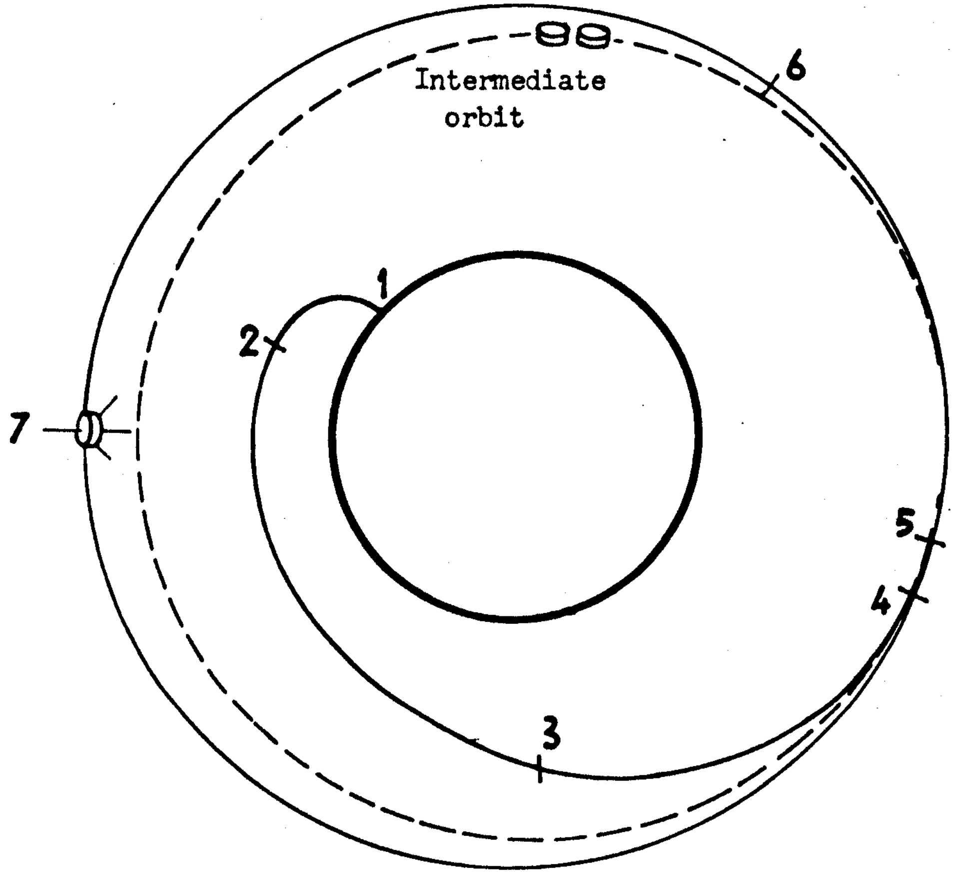


Fig.9 EARLY BIRD



1 Launching
2 Combustion of the final stage of the booster and separation of the rotating satellites
3 Transfer orbit
4 Cut-in of the apogee rocket, all satellites in intermediary orbit
5 Insertion into orbit, one satellite after the other
6 Stop of rotation of the positioned satellite, extension of the rods, and cut-in of the damper
7 Stabilization by gravity gradient accomplished

Fig.10

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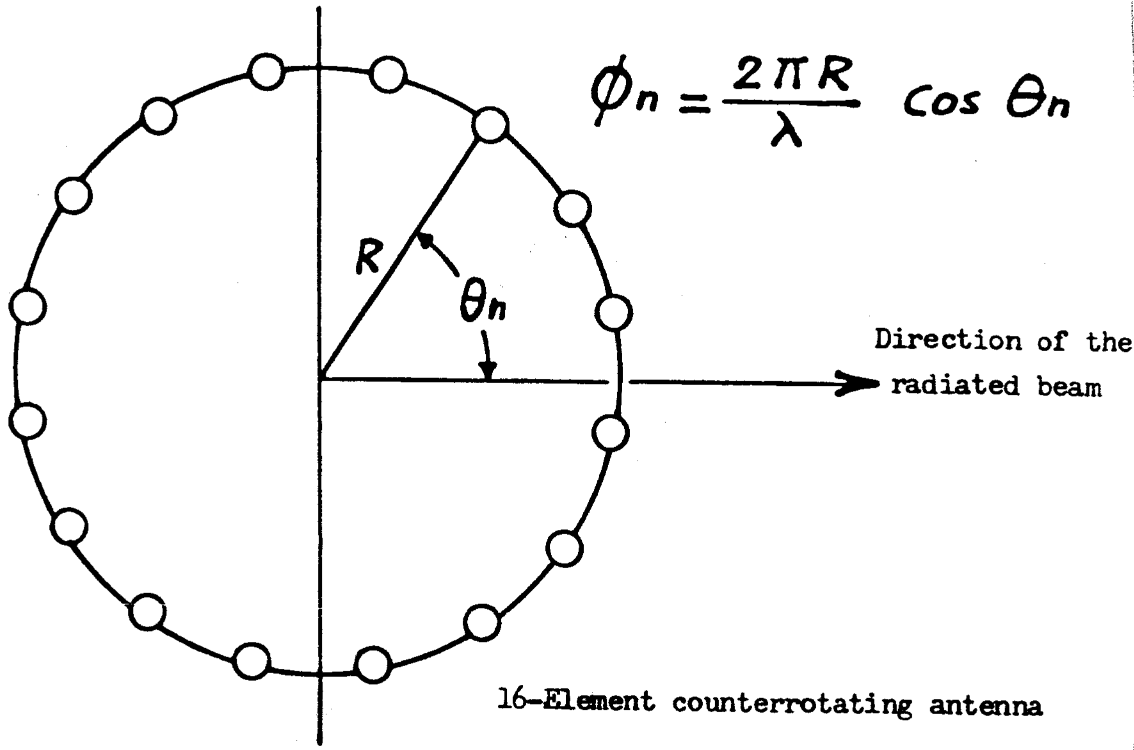


Fig.11

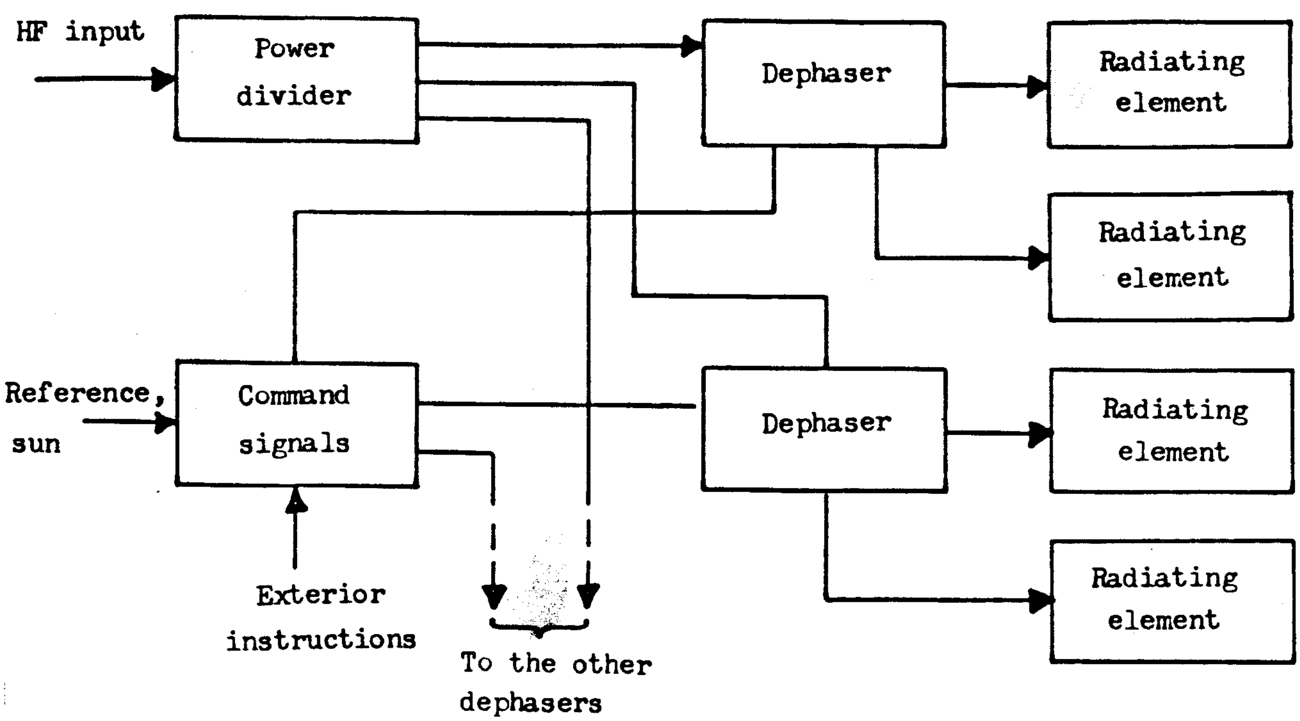


Fig.12

/33

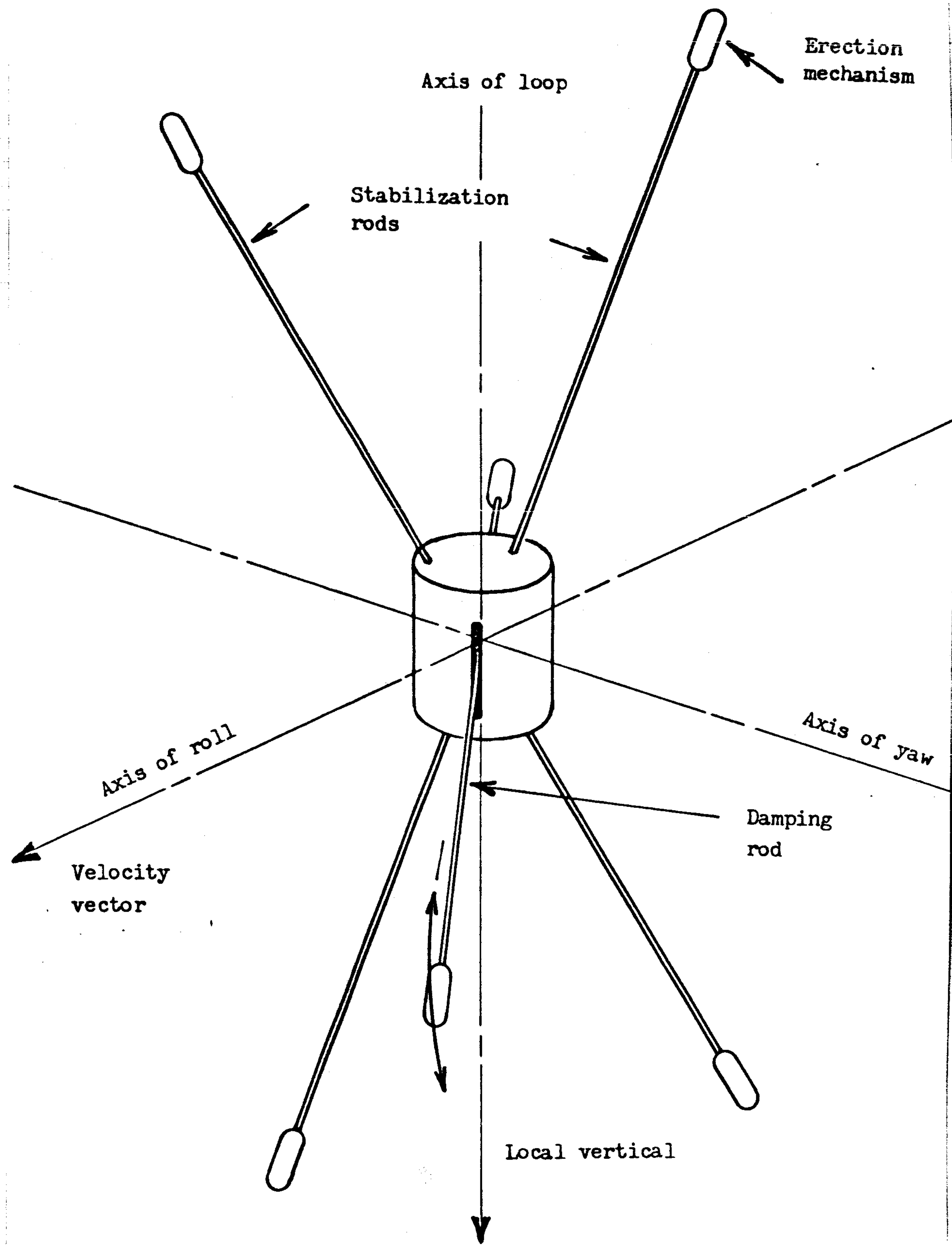
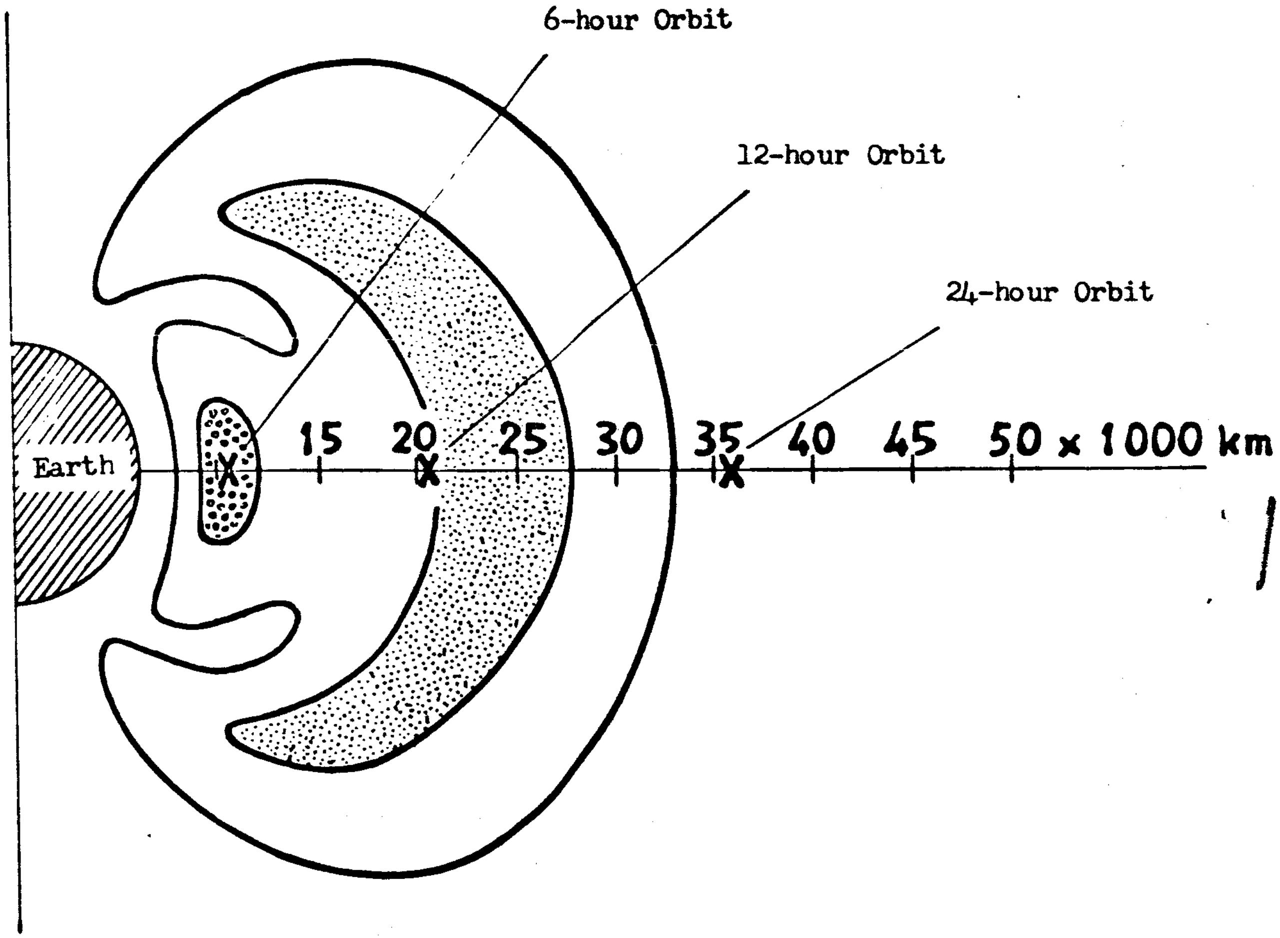
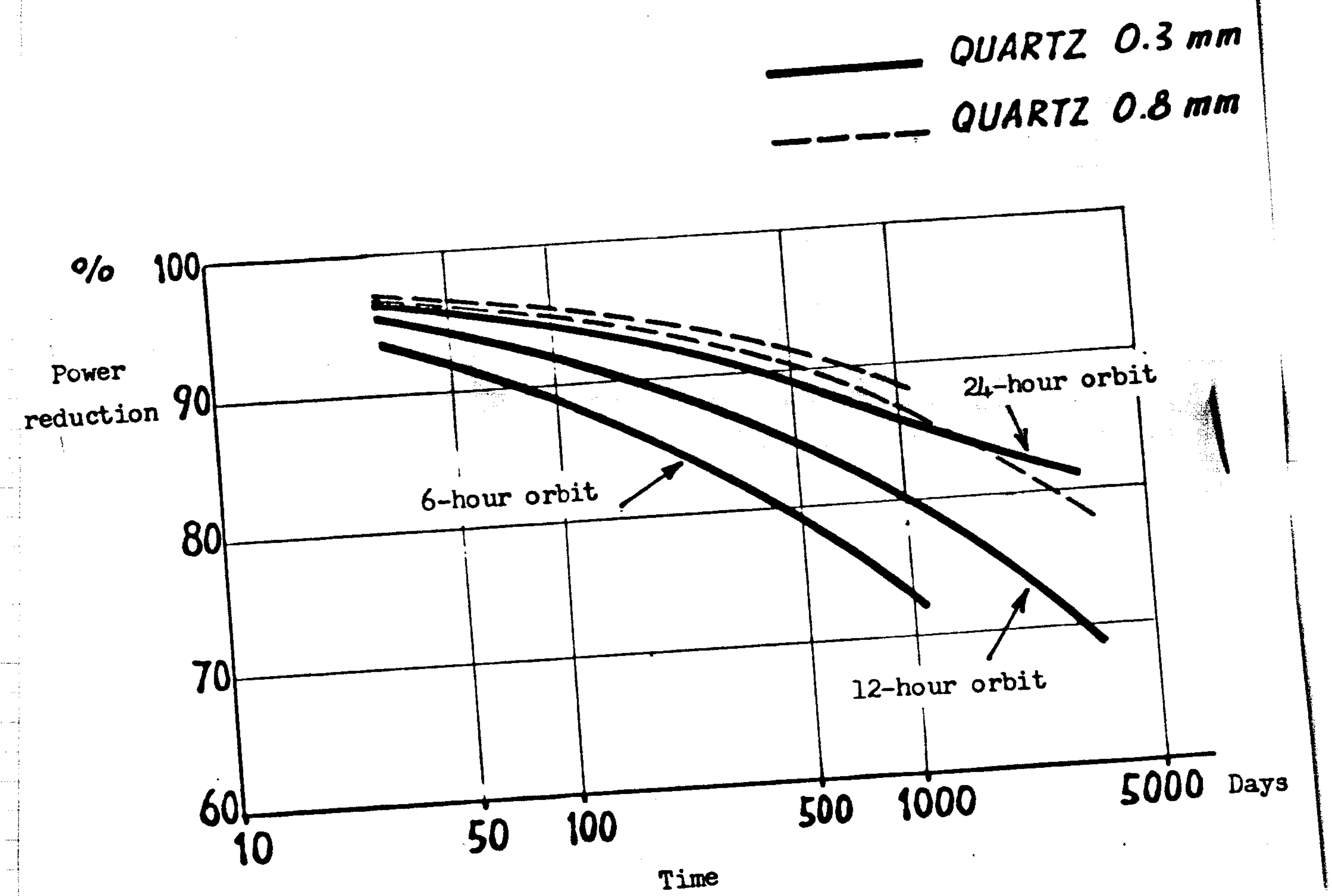

Erection
mechanism
Axis of loop
Stabilization
rods
Axis of roll
Axis of yaw
Damping
rod
Velocity
vector
Local vertical

Fig.13



6-hour Orbit
12-hour Orbit
24-hour Orbit
Earth
15
20
25
30
35
40
45
50 x 1000 km



QUARTZ 0.3 mm
QUARTZ 0.8 mm
%
100
90
80
70
60
Power
reduction
24-hour orbit
6-hour orbit
12-hour orbit
10
50
100
500
1000
5000
Days
Time

Fig.15

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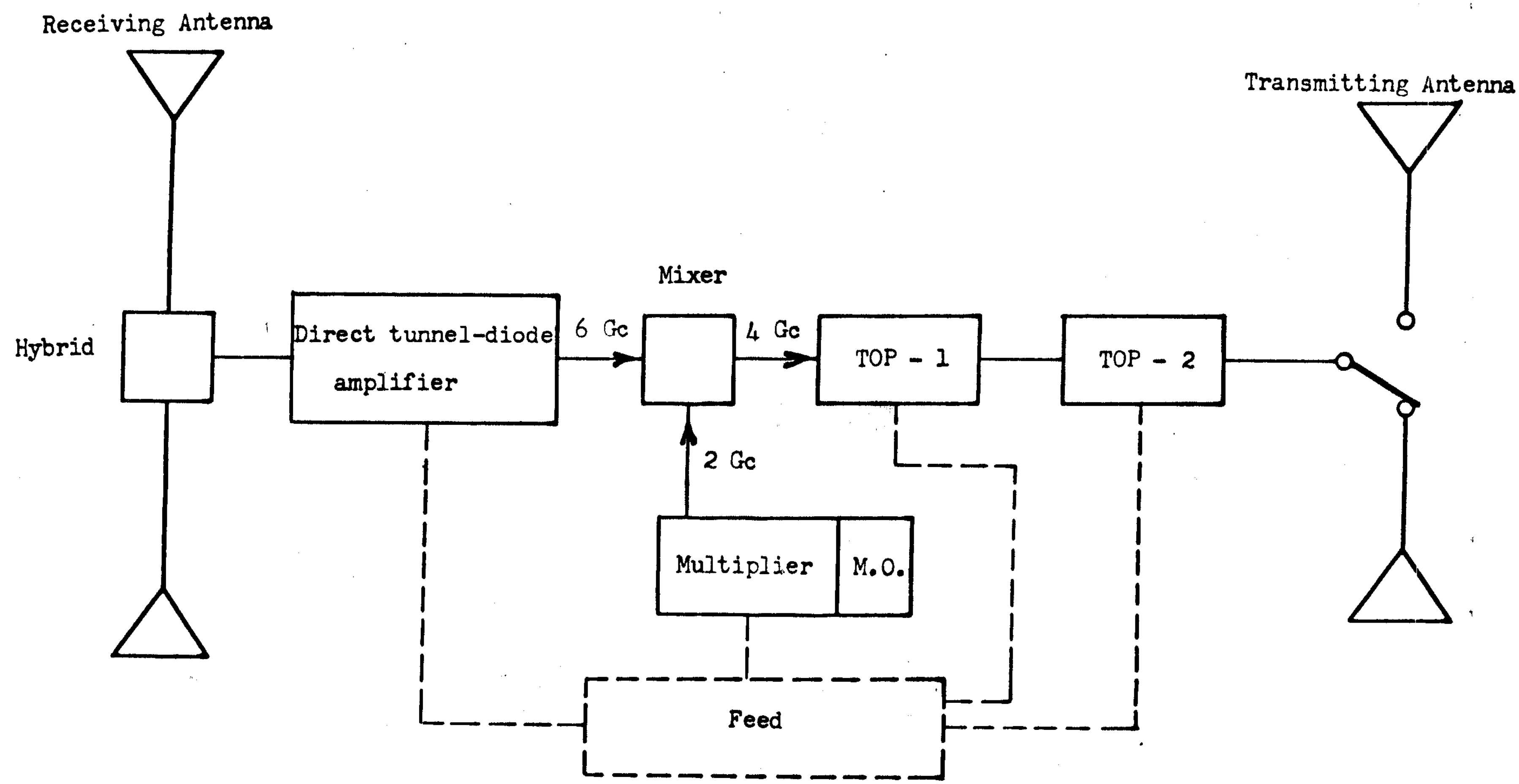
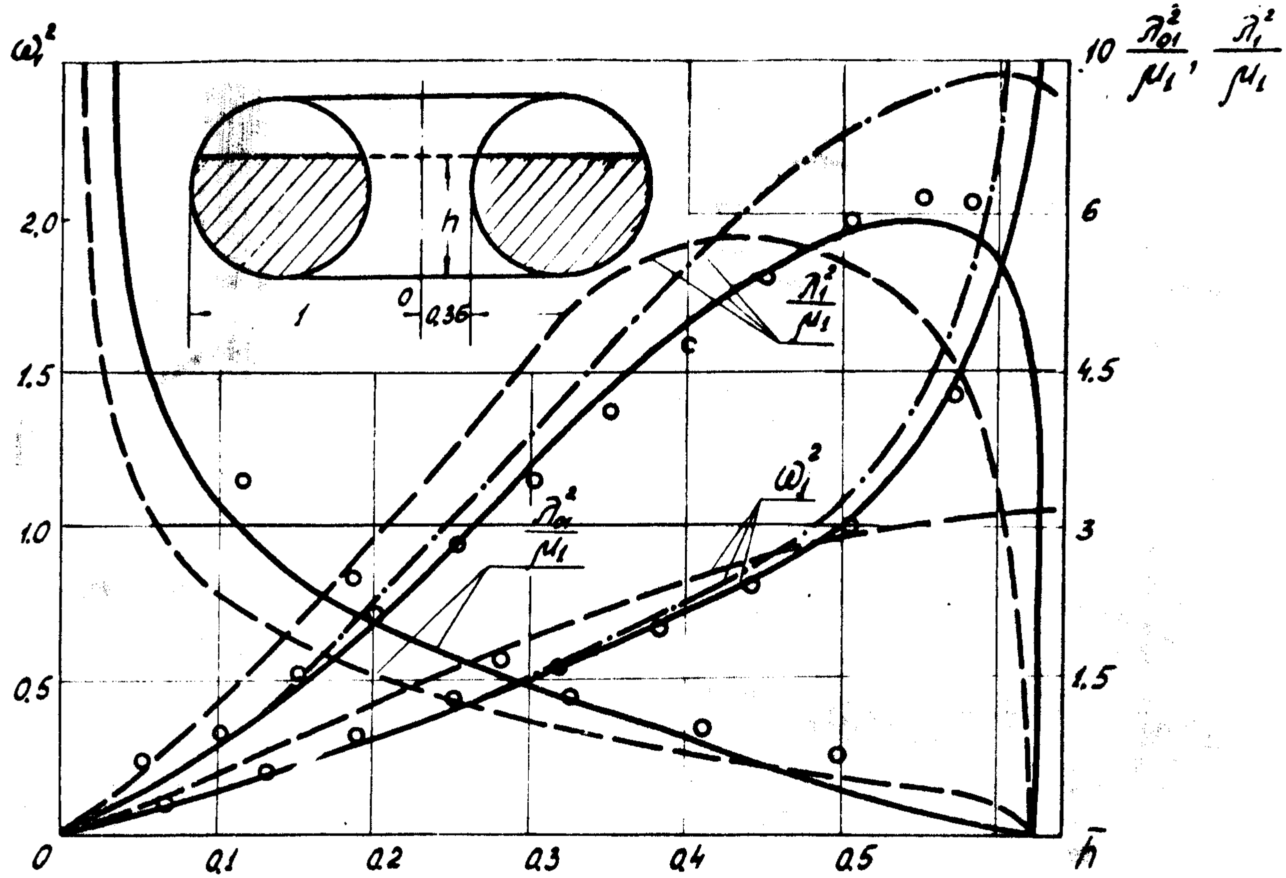


Fig.16 200 mc Band Repeater



Variational method (cylindrical functions)
Method of inscribed cylinders
Long-wave method
Experiment

Fig.10

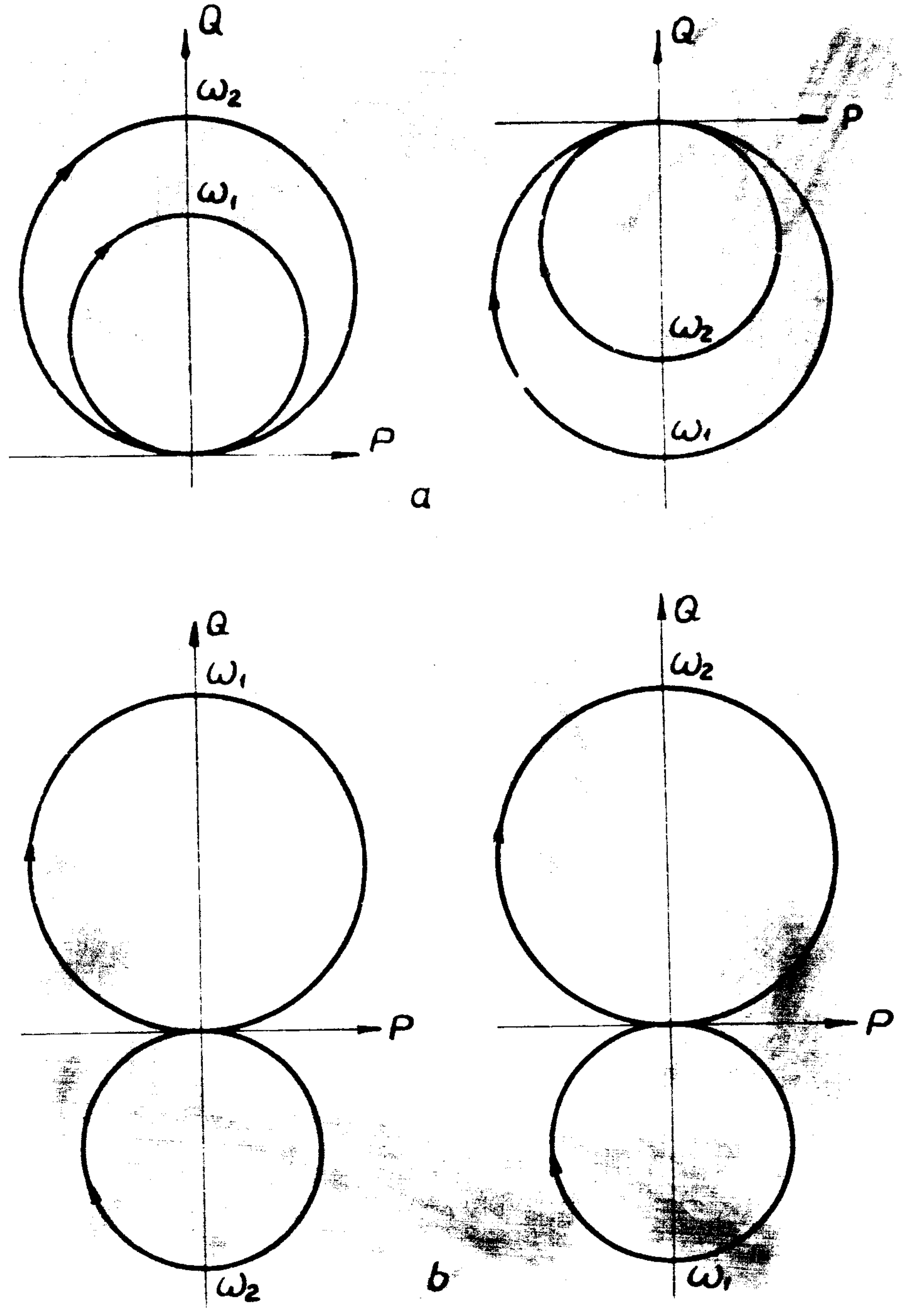


Fig.11

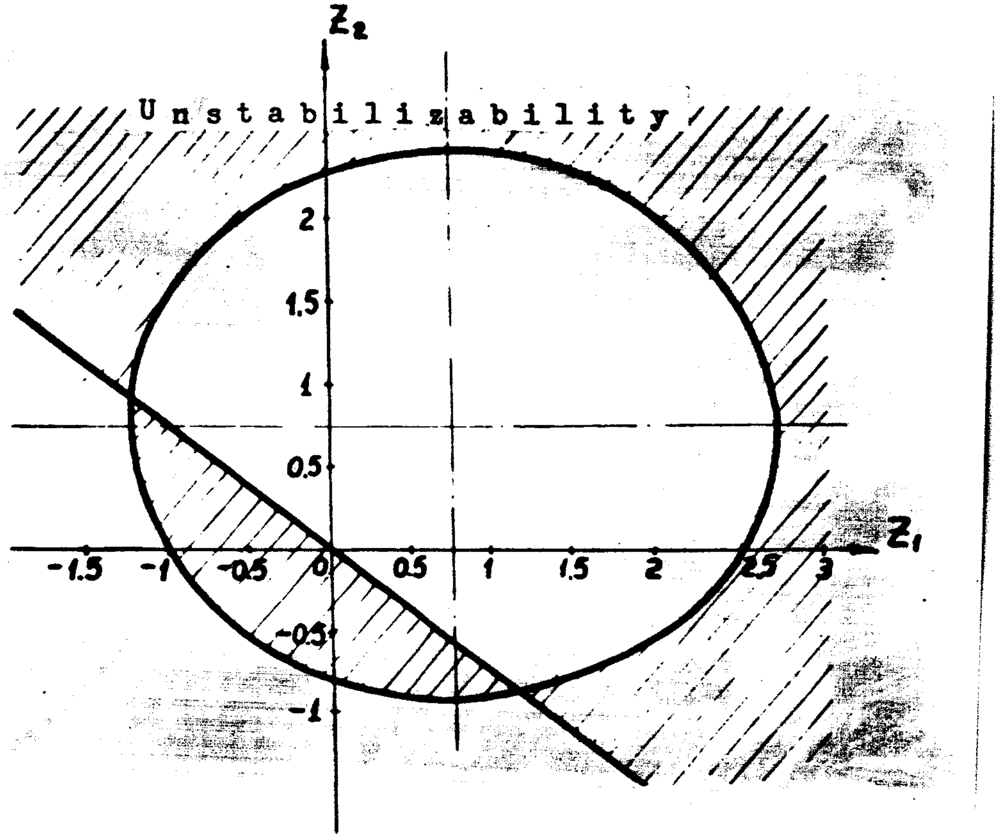

Z_2
Unstabilizability
2
1.5
1
0.5
-0.5
-1
Z_1
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
3

Fig.12

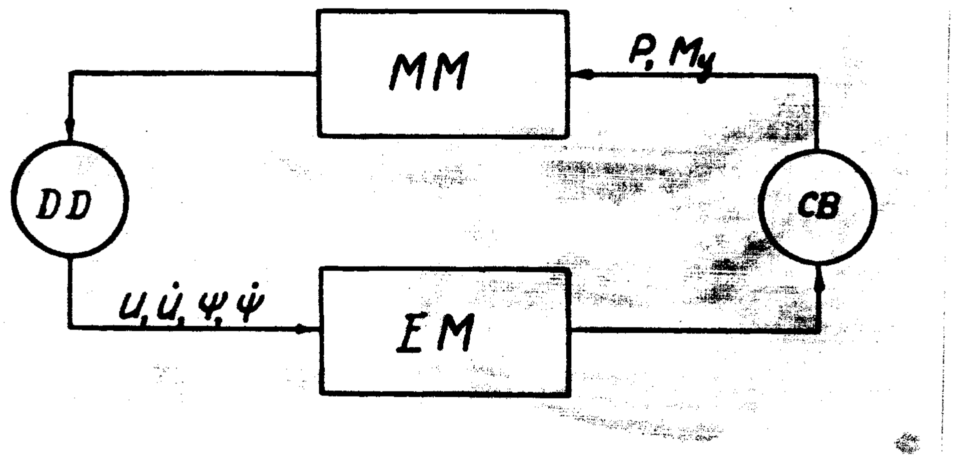

MM
P, M_y
DD
CB
$u, \dot{u}, \psi, \dot{\psi}$
EM

Fig.13